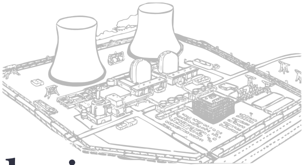

Introduction to benefit-cost analysis of safety investments

Eric Marsden

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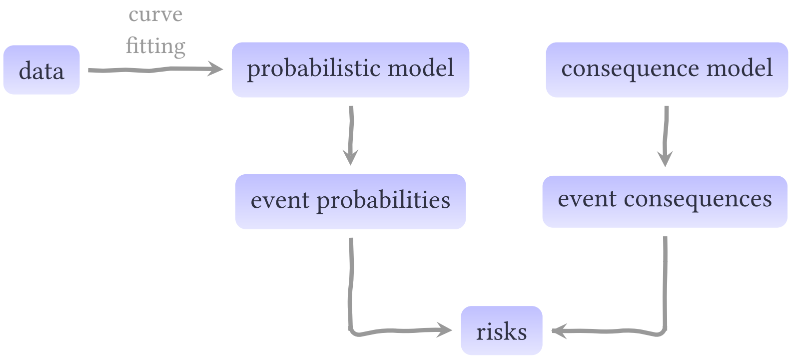
Would this project provide a net benefit to society?

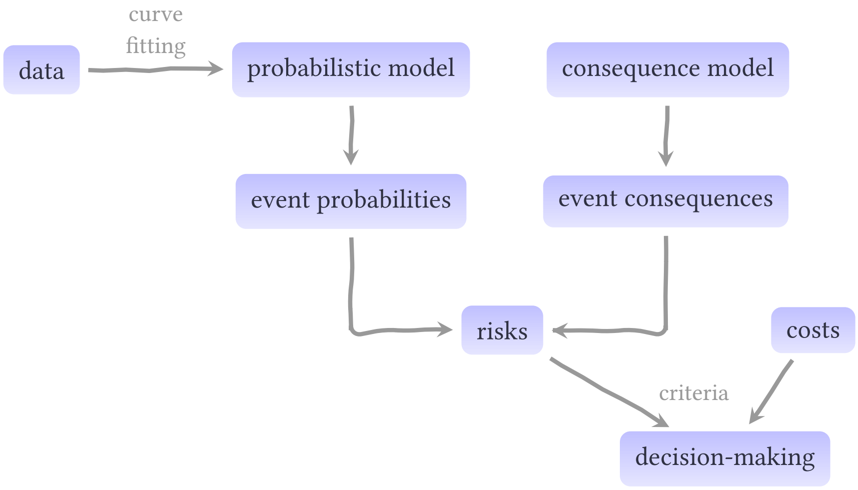
Learning objectives

1. Understand concepts of consumer surplus, willingness to pay, net present value
2. Understand how a benefit-cost analysis can be used to analyze the value of a safety investment
3. Be able to undertake a critical review of a benefit-cost analysis

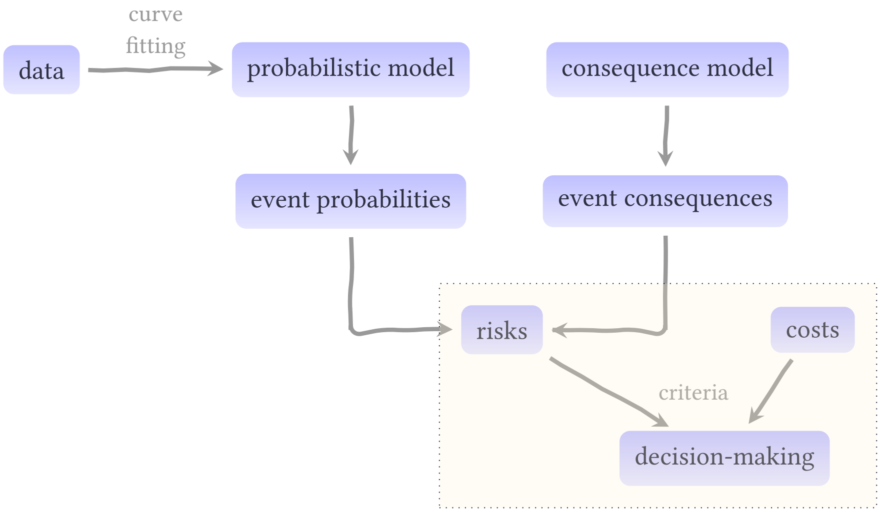
Where does this fit into risk engineering?



Where does this fit into risk engineering?



Where does this fit into risk engineering?



These slides

Context

- ▷ Public decisions on questions related to industrial safety must take multiple, **partially conflicting criteria** into account:
  - protection of human lives and health
  - environmental considerations
  - economic aspects: profits, jobs
  - societal demand for greater transparency
- ▷ Different people put different weights on these criteria
  - they are not expressed in the same units
- ▷ Decision-makers need tools to help them **establish tradeoffs** between these considerations and to **explain decisions** to stakeholders and citizens

Benefit-cost analysis

- Method to assess projects or decisions by comparing their **societal benefits** with their **cost**
- Societal benefits:
  - fewer fatalities and injuries in industry
  - improvements in citizens' health or well-being
  - cleaner air and water
  - economic development, jobs

- BCA is based on **monetization** of these criteria
  - based on citizens' preferences and their "willingness to pay" for marginal changes in risk

Applications of BCA

- Widely used in USA & Anglo-Saxon countries
  - analysis of transport projects (freeway, railway infrastructures)
  - environmental impact assessments
  - regulatory impact assessments
- Used at the EU level for **regulatory impact assessment**
  - example: impact of proposed *Clean Air For Europe* (CAFE) legislation was assessed using a BCA before decision to implement it

Principles of BCA

- Implementation of a project affects the utility of economic agents
  - consumers, firms, taxpayers…
- Consequences measured are **marginal variations in utility** of the affected agents
  - for a firm, measure the variation of profits
  - for an individual, measure “willingness to pay”
- **Decision rule**: BCA suggests that a decision should be taken if the net variation in utility is positive
  - *i.e.* the project has a net benefit to society

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Principles of BCA

- ▷ Benefits are valued according to the willingness of individuals to pay for them
  - is often more than they would actually need to pay
  - example: price of water supplied to a household is often less than willingness to pay
- ▷ Costs are valued according to willingness of others to pay for the resources involved
  - reflects the **best alternative forgone** (the *opportunity cost*)
  - example: a painter who paints their own house does not have to pay for labour, but their labour still has an opportunity cost as they could have been doing something else in the time spent

BCA is different from classical financial analysis

- Financial analysis only takes into account the **market price** (and total revenue) of supplying the service relative to its **cost of production**
- BCA *also* takes into account
  - the value of the service to consumers **beyond the price paid**
  - the cost beyond what is paid to the factors of production
- BCA should also take into account any *externalities*
  - externalities: other costs and benefits that affect people outside those involved in the transaction

Ethical framework for BCA

- **Utilitarian ethics**: “the greatest good for the greatest number”
  - maximization of welfare / utility
  - emphasizes results of an action, rather than following rules/principles
  - values are determined through personal preferences and casting dollar “votes”
  - example: vaccination of children against polio is “good” even if a (very small) number of children will suffer bad effects from the vaccine
  - benefit-cost analysis is compatible with this ethical framework
- **Duty-based (deontological) ethics**: adherence to rules that bind you to your duty
  - the intrinsic value of safety, or the moral imperative not to cause harm
  - an action is “good” if that choice of action would be good for all people at all times
  - not easily compatible with BCA

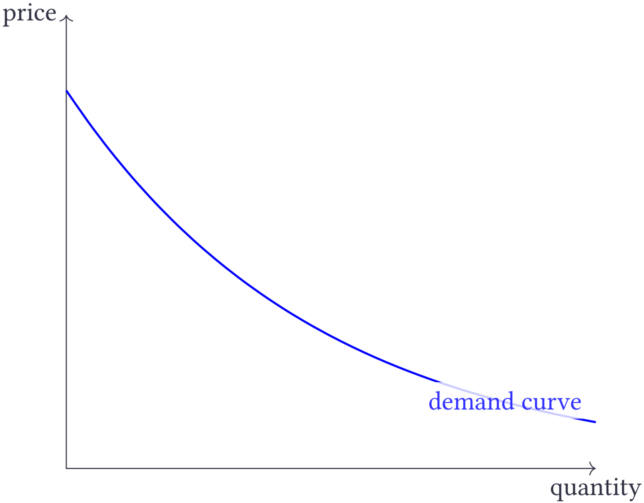
Willingness to pay

- Willingness to pay (WTP): what a person would be prepared to pay to benefit from a project that would improve their utility
  - *utility* represents satisfaction / happiness / abstract wealth
- If the project has negative consequences for a person, WTP will be negative
  - becomes a “willingness to accept” as compensation for the detrimental impact
- Philosophically different from classical “paternalist” approaches to public policy
  - BCA is a “democratic” or “populist” approach
  - value is determined by what consumers are willing to pay for an amenity, not what a politician or an expert thinks the value should be

Willingness to pay for a market good

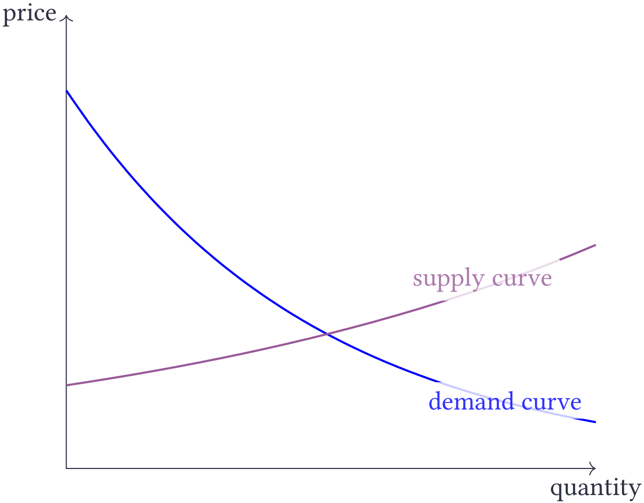
- ▷ Willingness to pay is not simply market price × consumption
- ▷ Market price is the *minimum* amount that consumers who buy the good are willing to pay for it
- ▷ Willingness to pay for a project that affects consumption of a market good can be estimated by the variation of the *consumer surplus* and the *producer surplus*
  - consumer surplus = WTP − actual price
  - measures the utility that consumers derive from their consumption of goods and services, or the benefits they derive from the exchange of goods

Variation in surplus and net social benefit of a market good



For market goods, the “law of demand” states that decreasing the price increases demand (the amount sold).

Variation in surplus and net social benefit of a market good



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Increasing price generally leads to an increase in the quantity supplied (lower marginal costs per unit).

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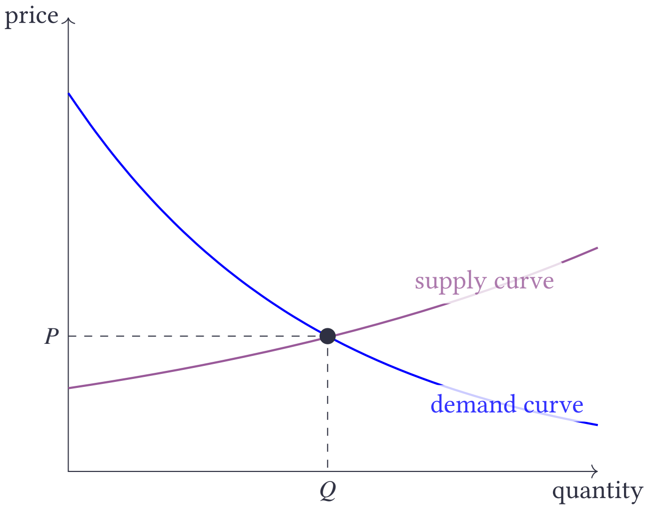

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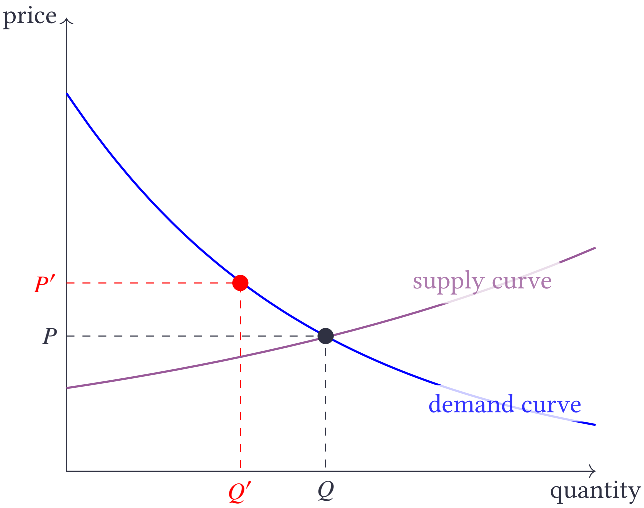

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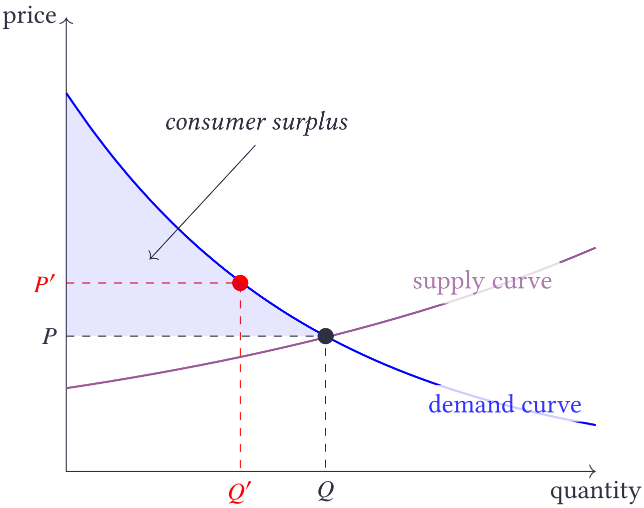

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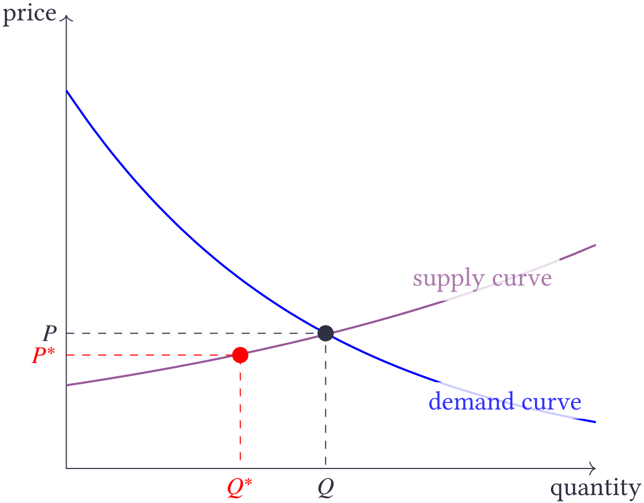
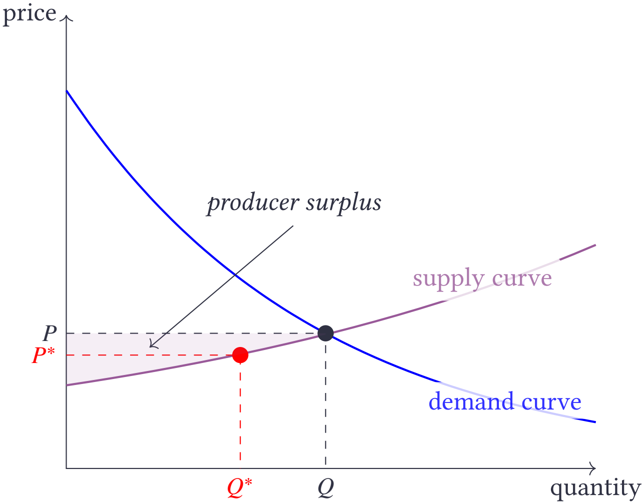
The set of all these differences between points on the demand curve and the equilibrium price is the *consumer surplus*.

Variation in surplus and net social benefit of a market good



At quantity Q^*, some producers would be willing to produce for a lower price P^*. The difference $P - P^*$ is their surplus.

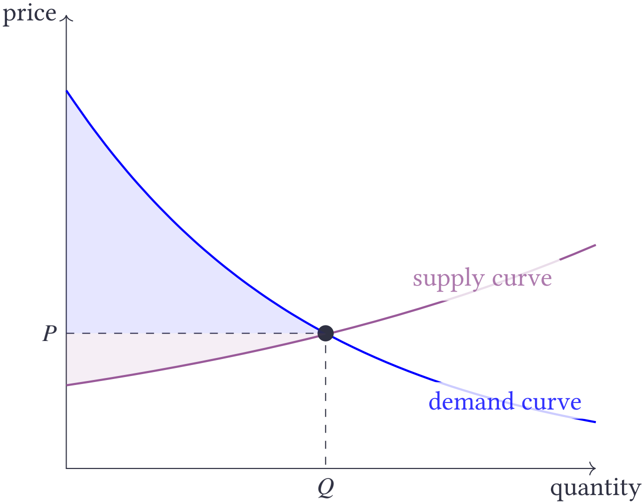
Variation in surplus and net social benefit of a market good



At quantity Q^*, some producers would be willing to produce for a lower price P^*. The difference $P - P^*$ is their surplus.

The set of points between the supply curve and the equilibrium price is the *producer surplus.*

Variation in surplus and net social benefit of a market good



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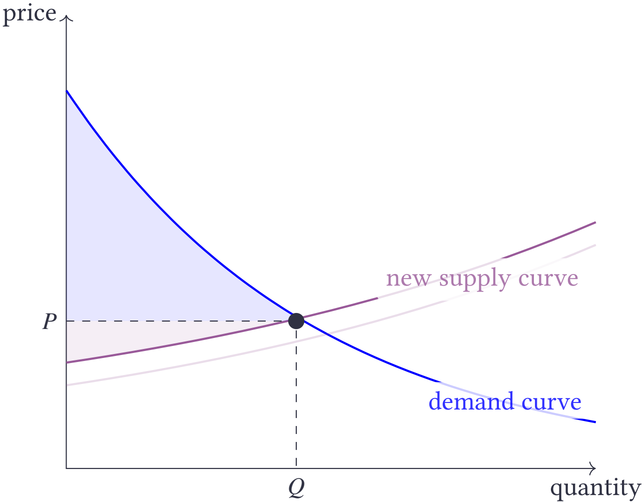
The set of points between the supply curve and the equilibrium price is the *producer surplus*.

The sum of the consumer surplus and the producer surplus is the *net social benefit* of this market good.

Variation in surplus and net social benefit of a market good



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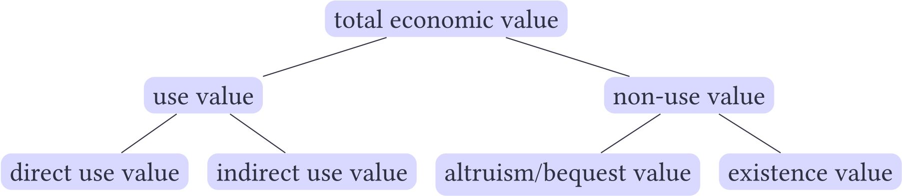
The set of points between the supply curve and the equilibrium price is the *producer surplus*.

The sum of the consumer surplus and the producer surplus is the *net social benefit* of this market good.

A change to the supply curve changes the size of the net social benefit. This delta must be counted as a benefit or a cost in a BCA.

Types of environmental value



- ▷ **direct use value**: use for farming, recreation
- ▷ **indirect use value**: values people hold for the services provided by species and ecosystems
  - pest control, water quality improvement, pollination...
- ▷ **altruism value**: satisfaction of knowing that other people have access to nature's benefits
- ▷ **bequest value**: relating to future generations
- ▷ **existence value**: satisfaction of knowing that a species or ecosystem exists
  - altruism towards biodiversity, ethical position on importance of other species

Willingness to pay for a risk reduction

- ▷ A project may affect the level of **mortality risk** to which individuals are exposed
- ▷ Need to monetize an individual's willingness to pay for a **marginal risk reduction**
- ▷ Extrapolated over a large population, leads to the concept of the "value of a statistical life" (VSL) or "**value of preventing a fatality**"
- ▷ If VSL = 5 M€:
  - individual willing to pay 5€ to reduce her current mortality risk by 1 in a million
  - individual willing to accept 5€ to increase her current mortality risk by 1 in a million
  - population of 1 million willing to pay/accept 5 M€ to prevent/accept one expected fatality
- ▷ VSL is **not** what society would be willing to pay to save an *identified* life!
  - not a measure of the intrinsic "worth" of an individual
  - VSL is sometimes seen as an immoral notion, but its value is implicit in any public spending on safety (*e.g.* prevention of road fatalities)

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Implicit VSL: example

- The French government spends around 3420 M€ per year on road safety
  - police enforcement, speed cameras, education, improvement of road infrastructure, research…
- Around 3500 road deaths per year, and 70 000 injuries
  - 54 fatalities per million inhabitants per year
- Let's assume that this spending is effective
  - more spending would lead to fewer fatalities, and less spending to more fatalities
- Implicit **value of a prevented fatality** is $\frac{3420}{3500} \approx 1$ M€

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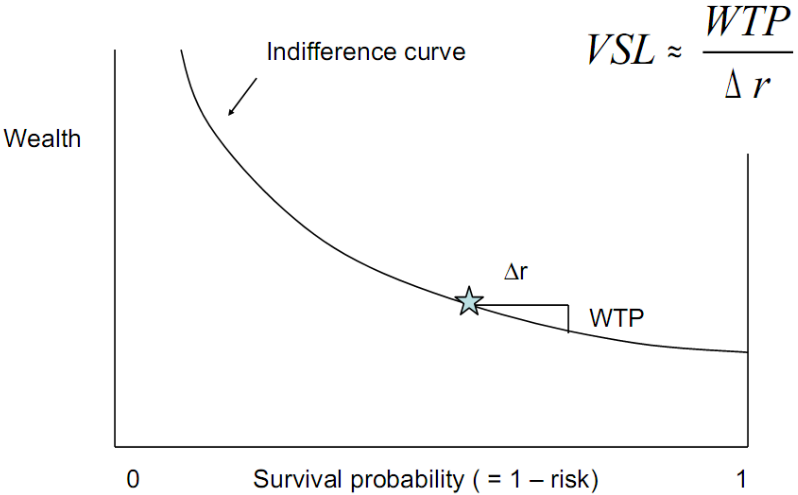
Wealth vs. mortality risk



Determinants of VSL

- VSL depends on
  - baseline risk (lower for higher "background" risk levels)
  - income and wealth (higher for wealthier individuals)
- May depend on the type of risk
  - acute or chronic, "voluntary" or "involuntary"
  - WTP to reduce risk of fatal degenerative disease 30% larger for cancer than for other disease [Hammitt & Liu 2004]
- Typical values between 1 and 6 M€ in western countries
  - value of 2.5 M€ recommended by EU for environmental impact assessments

> VSL is typically higher than compensation paid out to dependants of victims of fatal accidents. Insurance compensation is typically calculated based on "lifelong earnings": how much the victim would have earned during their remaining working years.

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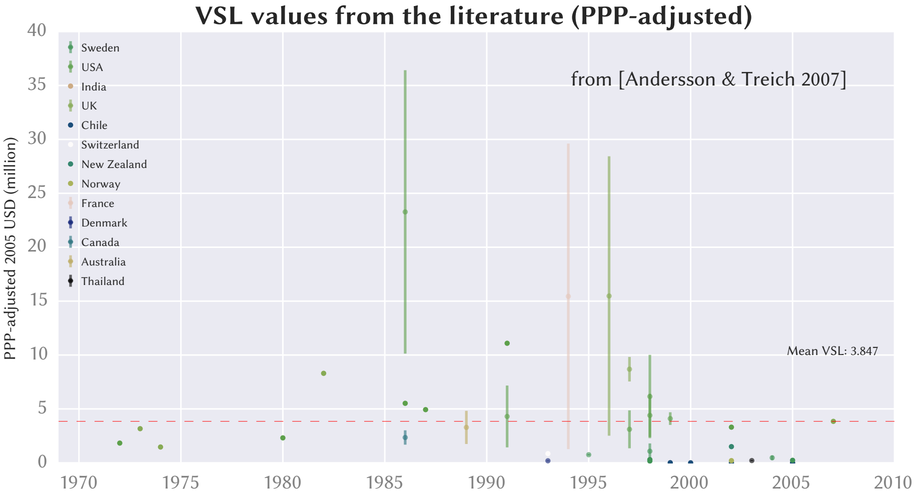
VSL in the literature



Data from *The Value of a Statistical Life*, H. Andersson & N. Treich, Handbook in Transport Economics, Edward Elgar, 2011, online at toulouse.inra.fr/lerna/treich/VSL.pdf

Factors affecting VSL

- Population characteristics
  - total baseline risk
  - income and wealth
  - other social, cultural, economic, demographic factors
- Risk characteristics
  - cause of death: *e.g.* acute trauma or chronic disease (cancer premium)
  - involuntariness
  - latency
  - size of risk change
- In most benefit-cost analyses, these factors are not taken into account
  - avoids some potential political/ethical issues with BCA

Effects of attributes of risk on VSL

- ▷ Fatal risks differ in ways that affect perception & tolerance
- ▷ Consequences: not all modes of death are perceived in the same manner
  - morbidity, time to prepare, gruesomeness
- ▷ Ambiguity aversion: people prefer known to unknown probabilities
- ▷ "psychometric attributes" of risk
  - familiarity, knowledge, control, catastrophic potential, equity

→ slideset on risk perception at risk-engineering.org

Phases of a BCA

Phases of a BCA

1. Specify the different scenarios or projects being compared
2. List the economic agents concerned, for whom the consequences will be estimated (define the perimeter of the study)
3. List the consequences and choose indicators to measure them
4. Estimate the consequences quantitatively, over the period where the project's effects will be felt
5. Monetize the consequences
6. Discount costs and benefits to obtain the *Net Present Value* of each scenario
7. Undertake a sensitivity analysis for the main uncertain parameters
8. Make a recommendation

1. Specify the different scenarios

▷ In theory, all possible scenarios should be envisaged
  - and compared with the optimal allocation of funds in the present situation

▷ In practice, only a limited number of alternative choices can be studied
  - the optimal alternative is often difficult to determine

▷ The reference scenario is therefore often taken to be the *status quo*

2. Determine the concerned agents

- ▷ Choose groups of agents for whom the consequences will be estimated
- ▷ The results of a BCA depend on hypotheses concerning the perimeter
  - exclusion of actors whose preferences are socially unacceptable
  - inclusion of the preferences of future generations
- ▷ Not always trivial
  - environmental regulation: should the consequences outside the country's borders be considered?
  - crime prevention policy: should the utility of criminals be taken into consideration?

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3. List consequences and their measures

- ▷ List all relevant impacts of the project
- ▷ For each impact, specify a **measure** (monetary units, number of fatalities avoided, number of work hours lost or gained…)
- ▷ Consequences on a non-market good (biodiversity, landscapes…) will only be counted if these goods affect the utility of an economic agent
  - Example: the negative consequences of the construction of a wind farm on migratory birds are only taken into account if there are bird lovers who are willing to pay to avoid the construction of the farm
- ▷ Impacts can be considered only if the **causal relationship** between the characteristics of the project and the utility of the affected agents is known

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3. Example consequences

- Direct costs
  - capital costs (new equipment & machines, building work…)
  - operating costs (man-hours, training, verification & validation, audits, safety case, modelling, extra administrative overheads, emergency plans)
  - transaction costs (transfer of information, legal costs…)
- Indirect costs
  - costs associated with a change to the process
  - loss of competitiveness; decreased productivity
  - opportunity cost of delayed investments
  - strategic consequences
- Benefits
  - reduction in potential losses and damages (lives, health, goods…)
  - reduced insurance premium
  - productivity gains
  - positive impact on reputation

4. Quantify the consequences

- ▷ A project has impacts several years after its implementation, whose **consequences over time** must be estimated
- ▷ It may be difficult to anticipate all the changes in behaviour of affected individuals
  - Example: legislation requiring car manufacturers to produce safer cars has led some drivers to take more risks when driving *(negative compensation effect)*
  - Example: legislation requiring children to wear a helmet when riding a bicycle can incite parents also to wear a helmet *(positive indirect effect)*
- ▷ Certain predictions require scientific knowledge which is unavailable or very uncertain at the time when the project is being evaluated
  - Example: controversy over global warming

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5. Monetize the consequences

- Give a monetary value for each of the impacts
- For impact on consumption of a market good, we can estimate variations in utility (consumer surplus) using the market price and an estimation of the demand function for that good
- For non-market goods or services, or in the presence of market failures, use alternative estimation methods
  - contingent valuation
  - method of transport costs
  - hedonic price method
- These methods estimate a person's *willingness to pay* for a specific characteristic of a product, or to benefit from a non-commercial good
  - air quality, quality of a landscape, level of industrial risk…

5. Monetizing impacts

- **Revealed preference**, based on observed behavior
  - travel cost: values of related, complementary activities
  - hedonic: values implicit in observed prices, usually housing
- **Stated preference**, based on intended/declared behavior
  - choice modeling: bundles of characteristics, including price, are ranked and analyzed
  - contingent valuation: a given change in quantity is offered at various prices, and usually presented as a referendum
- All methods involve quite sophisticated statistical modeling and estimation
  - all are controversial and relatively expensive to undertake carefully

Comment on cost of safety equipment

- Cost of safety equipment is not linearly related to level of performance
- Increasing performance level by a factor of 10 often multiplies cost by a factor of 1000
  - Example: moving from SIL 2 to SIL 3 rating (safety instrumented systems)

6: Discount costs & benefits to obtain NPV

- Consequences of considered scenarios are often spread over several years, and the time horizons sometimes differ

- In order to obtain a common measure of effects, we discount costs and benefits for each scenario

- If one can invest money with a zero-risk interest rate of 4%, obtaining 100€ in one year is equivalent to having 100 / (1 + 0.04) = 96.15€ today

- Adopt today's perspective and discount future benefits and costs to obtain the Net Present Value (NPV) of the project:

$$NPV = \sum_t \frac{B_t - C_t}{(1+i)^t}$$

- If the time horizons of the scenarios differ, they must be adjusted
  - or compare the *annual net present value*

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6: Discount costs & benefits to obtain NPV

- ▷ Net Present Value = the value today of money you will receive in the future

- ▷ The net present value of an income stream is the sum of the present values of the individual amounts in the income stream
  - each future income amount in the stream is discounted
  - discounting: divide by a number representing the opportunity cost of holding capital from now (year 0) until the year when income is received
  - opportunity cost: how much you would have earned investing the money somewhere else, or how much interest you would have had to pay if you borrowed money

- ▷ NPV = PV(benefits) − PV(costs)

- ▷ **Decision rule**: choose the project with **largest NPV**

Discounting & NPV: example

	Project A (€)	Project B (€)	Project C (€)
Today	-100 000	-100 000	-100 000
in 1 year	+25 000	+80 000	0
in 2 years	+25 000	+10 000	0
in 3 years	+25 000	+10 000	0
in 4 years	+25 000	+10 000	0
in 5 years	+25 000	+10 000	130 000
NPV ($i = 2\%$)	+18 289	+15 943	+20 099
NPV ($i = 8\%$)	+1 178	+5 286	-4 446

Project ranking is reversed by a 6 point change in discount rate…

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6. Discounting

- The choice of the discount rate has a significant impact on the NPV
  - discount rate can also be seen as representing a person's or a society's temporal preferences or **degree of care for future generations**
- Discount rate for public projects in France is 8%
  - set in 1985 by the Commissariat Général du Plan
- Some people argue that lives saved in the future should not be discounted
  - what does this mean in practice, given that future population is theoretically infinite?
- Current recommendations are to use a discount rate of 4%, decreasing to 2% for very long-term projects (more than 30 years)
- The discount rate is an important parameter to include in the sensitivity analysis (step 7)

7. Undertake an uncertainty analysis

- A BCA comprises numerous uncertainties, approximations and hypotheses
  - potential consequences
  - their monetization (preference elicitation)
  - consideration of time effects
- The **robustness** of the results of the analysis to the principal sources of uncertainty should be assessed (uncertainty analysis)
  - vary various parameters (VSL, discount rate, *etc.*) and see whether the ordering of NPV for the different projects changes
  - or compare the most pessimist and most optimistic scenarios
- The Monte Carlo method allows a distribution of net benefits to be calculated, considering the distribution of the various uncertain input parameters

→ *slideset on Monte Carlo methods for risk analysis at risk-engineering.org*

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8. Make a recommendation

- Generally the scenario with the greatest (annualized) Net Present Value is recommended
  - *i.e.* the scenario which leads to the greatest increase in the societal benefit
- Sometimes the benefit/cost ratio is used, but this decision rule has several defects:
  - does not lead to choosing the project which has the greatest net benefit
  - increases sensitivity to the way in which benefits and costs are selected
  - not robust with respect to uncertainty, especially concerning costs

Example application: zoning of industrial sites

- ▷ Many high-risk industrial sites are located close to urban zones
- ▷ Possible decisions:
  - relocate industrial sites elsewhere
  - implement safety mechanisms on industrial sites to reduce danger perimeters
  - move houses located in zones where risk is too high
  - reinforce housing located in medium-risk zones, improve civil protection system (mitigation)
  - prevent further urbanization close to industrial zones
- ▷ What tradeoff between these alternative strategies?

Conclusions

Advantages of the approach

- Aid for decision-makers
  - provides information on estimated impacts of a decision
  - limits of knowledge are made explicit; uncertainty is quantified
  - facilitates coherent policy with respect to different classes of risk
- **Increased transparency** of the decision process
  - assumptions and inferences are explicit, open to review and challenge
  - provides a "memory" of the elements considered in a decision
  - avoids "capture" of the decision by lobbies and by media influence
- More practical than notions such as "sustainable development", "precautionary principle"
  - based on values expressed by citizens (*populist* rather than *technocratic*)
- Helps to identify areas where improved scientific knowledge could be most useful to policy-makers

Limits of the approach

- ▷ Ethical issues
  - leads to uncomfortable notions such as the “value of a statistical life” (however, these are implicit in many political decisions)
  - analysis is anthropocentric
  - level of discounting to account for future generations is subject to debate
  - redistributive effects must be analyzed separately
- ▷ Practical issues
  - “irrational” nature of people’s reaction to certain risks (should public policy be based on citizens’ perception or on scientific “truth”?)
  - difficulty in assessing certain aspects of people’s preferences
  - cost of BCA studies may be too high for small projects

Key takeaways

- Benefit-cost analysis could be a useful tool to aid public decision-making on risk issues
  - improve the *efficiency* of public policy
  - lead to increased transparency of the decision-making process
  - structure public debate and improve public acceptance of decisions
- Only a tool that provides information
  - does not replace decision-makers!

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- Car crash on slide 16, `flic.kr/p/hZTNQp` (CC BY-ND licence)
- Mural on slide 40 by Blu, Cochabamba, Bolivia

THANKS!

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Further reading

- Book: *Cost-Benefit Analysis and the Environment: Recent Developments*, OECD publishing (2006, ISBN: 9264010041); free PDF available
- UK HSE principles for Cost-Benefit Analysis in support of ALARP decisions, `hse.gov.uk/risk/theory/alarpcba.htm`
- Article *Towards Principles and Standards for the Benefit-Cost Analysis of Safety* by S. Farrow and W. Kip Viscusi, Journal of Benefit-Cost Analysis, 2011

Feedback welcome!

Was some of the content unclear? Which parts were most useful to you? Your comments to `feedback@risk-engineering.org` (email) or `@LearnRiskEng` (Twitter) will help us to improve these materials. Thanks!

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